Performance Evaluation of Solar Water Heater by Using Flat Plate Collector and Evacuated Tubes with Fin Tube Using CFD

Prof. O.P Shukla[1], Deepanjal Kumar Gupta[2]
[1]*Corporate Institute of Science and Technology, Professor, RGPV Bhopal, MP, INDIA*
[2]*Corporate Institute of Science and Technology, Research Scholar, RGPV Bhopal, MP, INDIA*

Abstract- **In today's climate of growing energy needs and increasing environmental concern, alternatives to the use of non-renewable and polluting fossil fuels have to be investigated. One such alternative is solar energy. Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth.**

A solar water heater is a device that can be used to capture sunlight in order to heat the water in your pipes to be used for baths, showers; etc. Solar water heater plays an important role in energy conservation. Because of its efficiency is comparatively more than the electrical energy conversion. Solar water heater is a very simple device and efficient way to absorb energy from the sun rays and use it.

In this work design improvement of solar water heating temperature up to bathing in home and nursing home applications above home temperature method always follows an orderly step-by-step process. Finally compared analysis results with electric water heater materials and solar water heater materials. The solar collector model thus produced was put to test by simulated effect of radiation due to sun , while circulating water through it at constant mass flow rates , the evacuated tubes are imparted with fin .The SWH efficiency was as high as 56% as compared to SWE with simple tube . These types of solar water heaters can easily be used to heat pool water. A flow rate comparable to that of 0.2 Lpm is best for heating. The heaters are to be used intermittently for heating a batch of water till 15-20 minutes until the efficiency drops down and then fresh water be circulated through it. A cycle like this would give us the maximum output in minimum time.

Index Terms- Solar water heater, Fins, CFD, Efficiency, Wattage, Ansys 14.5.

I. INTRODUCTION

1.1 Solar Water Heating System

Solar water heating system is a device that uses solar energy to heat water for domestic, commercial, and industrial needs. Heating of water is the most common application of solar energy in the world. A typical solar water heating system can save up to 1500 units of electricity every year, for every 100 litres per day of solar water heating capacity.

1.1.1 Parts of the Solar Water Heating System

- A solar water heating system consists of a flat plate solar collector, a storage tank kept at a height behind the collector, and connecting pipes.
- The collector usually comprises copper tubes welded to copper sheets (both coated with a highly absorbing black coating) with a toughened glass sheet on top and insulating material at the back. The entire assembly is placed in a flat box.
- In certain models, evacuated glass tubes are used instead of copper; a separate cover sheet and insulating box are not required in this case.

1.1.2 Working of a solar water heater

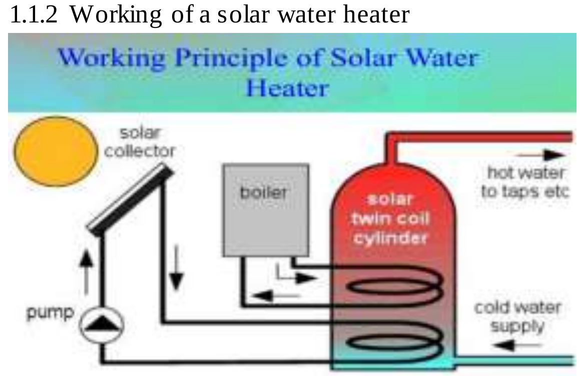

Figure 1 Working principle of solar water heater.

- The system is generally installed on the roof or open ground, with the collector facing the sun and connected to a continuous water supply.
- Water flows through the tubes, absorbs solar heat and becomes hot.
- The heated water is stored in a tank for further use.
- The water stored in the tank remains hot overnight as the storage tank is insulated and heat losses are small.

1.1.3 Uses of solar water heater

- SWHs can be used at homes for producing hot water that can be used for bathing, cleaning, and washing. Solar water heaters (SWHs) of 100-300 litres capacity are suited for domestic application. Larger systems can also be used for a variety of industrial applications. Hot water at 60-80oC could be obtained through use of solar water heaters.
- Fuel Savings: A 100 litres capacity SWH can replace an electric geyser for residential use and saves 1500 units of electricity annually.
- Saves cost on power generation - The use of 1000 SWHs of 100 litres capacity each can contribute to a peak load saving of 1 MW.
- Environmental benefits - A SWH of 100 litres capacity can prevent emission of 1.5 tonnes of carbon-dioxide per year.
- Payback period - SWHs have a life span of 15-20 years. The payback period is about 3-4 years when electricity is replaced, 4-5 years when furnace oil is replaced and 6-7 years when coal is replaced.

1.1.4 Classification of solar water heating system

They can be classified into three main categories:

a) Active systems which use pumps to circulate water or a heat transfer fluid,
b) Passive systems (or Thermo syphon systems) which circulate water or a heat transfer fluid by natural convection and
c) Batch systems using a tank directly heated by sunlight.

II. LITERATURE REVIEW

Use of solar energy for water heating is the most common application, mostly three types of solar collectors based solar water heaters (SWH) are available in the market viz. flat plate collector (FPC), evacuated tube collector (ETC), compound parabolic collectors (CPC). Dharuman et al. [2010], designed, constructed and did the experiments on water heating device and its performance was evaluated under various typical operating conditions. Nahar [2011], did the comparative analysis of Cu– Al fin with Cu–Cu fin in flat-plate collectors to test solar water heater. Anant et al. [2012], investigated and analyzed the performance of thermal energy storage based 27 solar water heater. Rakesh and Rosen [2013] worked on the thermal performance evaluation of an integrated solar water heater with a corrugated absorber surface.

Morrison et al. [2014] evaluated the characteristics of evacuated tube based solar water heaters also made an assessment of the circulation rate through single ended tubes. Assuming that there was no interaction between adjacent tubes in the collector array they developed a numerical model of the heat transfer and fluid flow inside a single ended evacuated tube and the simulation study had been performed. The computational domain used in this study was single-ended thermosyphon with a constant pressure condition applied across the open end. In this study the computational fluid dynamics (CFD) model was validated against Particle Image Velocimetry (PIV) measurements. Experimental and simulation results showed that there was a good agreement in a number of qualitative and quantitative parameters, such as the location of the peak velocity, the peak velocity of the heated fluid stream, the cross-over point between the two opposing streams and the flow structure as the hot fluid rises up the tank.

Xiaowu and Ben [2014] evaluated the performance of domestic scale solar water heater based on exergy analysis. Three procedure theory as presented in the paper exhibits great advantages as compared with other theories of energy analysis. From the study, it was shown that the proper insulation of collector and storage barrel were important as exergy losses due to imperfectly thermal insulation in collector and exergy losses due to imperfectly thermal insulation in storage barrel cannot be avoided. The exergetic efficiency of domestic-scale water heater was found to be small due to low quality of output energy and exergy losses storage barrel.

Luminosu and Fara [2015] determined the optimal operation mode of flat plate collector using exergy analysis through simulation. In this study the exergy analysis 28 of a flat-plate solar collector based on the assumption that temperature at inlet fluid = environment temperature = constant has been developed. The statistical data for the solar radiation of a given area was used and the optimal values for the characteristic quantities of the flat-plate solar collector had been obtained by developing the exergy analysis for the selected model. The hot water supplied by this collector would be used either directly, for example, for retarded, or showers, storing it in an insulated tank. Another interesting application of this approach would use the swimming pools model: alternatively, the hot water supplied by the solar collector would be discharged in one of the swimming pools. That is open circuit condition for the use of this solar collector is recommended.

Budihardjo et al. [2016] developed a correlation for natural circulation flow rate through single ended water-in-glass evacuated tubes mounted over a diffuse reflector. Further, the numerical simulation showed that when the heat input was concentrated on the top circumference of the tube, as in the case with collectors mounted over a diffuse reflector. The effect of circumferential heat flux distribution on the circulation flow rate through the tubes was not significant; therefore, the correlation could be used to predict the flow rate at any time of day. Different flow structures were observed in the tube when a concentrating reflector was used underneath the collector.

III.METHODOLOGY

The geometry of at exchanger performing the simulation study is taken form one of the research scholar's J.J Jayakanth (2016) paper with exact dimension excluding fins dimensions. The part of model was designed in ANSYS (Fluent) workbench 14.5 software. The geometric dimension of the shell and tube heat exchanger is shown in the Table 1and 2.

Table 1: Geometric Dimension of the collector

Collector length	77cm
Collector breath	46cm
Collector height	11cm
Absorber thickness	0.5cm

Table 2: Geometric Dimension of the Tube

MATERIAL	Copper
INTERNAL DIAMETER	0.7 cm
OUTER DIAMETER	0.9cm
LENGTH	485 cm

Table 3: Geometric Dimension of fin

MATERIAL	Copper
SQUARE FIN	1 cm* 1cm
LENGTH	485 cm

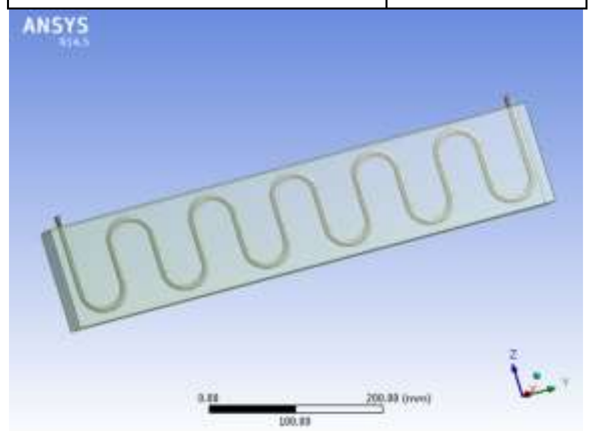

Figure 2 Geometry of Solar water heaters.

MESHING

By, default, a coarse mesh is generated by ANSYS software. Mesh contains mixed cells per unit area (ICEM Tetrahedral cells) having triangular and quadrilateral faces at the boundaries. However, for current problem the mesh having 412568 nodes and 1640288 elements in generated.

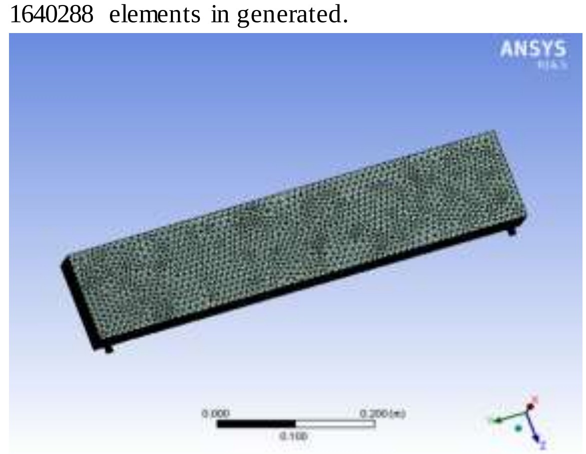

Fig 3: Meshing of solar water heater

NAME SELECTION

A different part of the solar water heater and fluid flowing inside the solar water heater is selected and the names are given to them so that boundary conditions can be applied on different boundary.

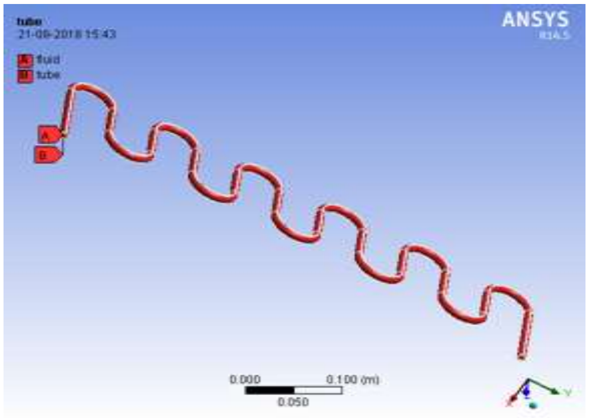

Figure 4: Name Selection of fluid flow and tube

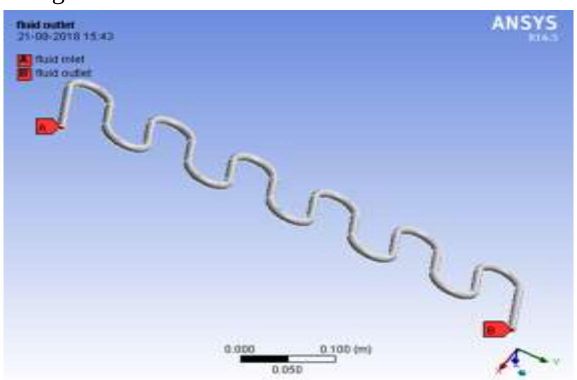

Figure 5: Name Selection of fluid inlet and outlet

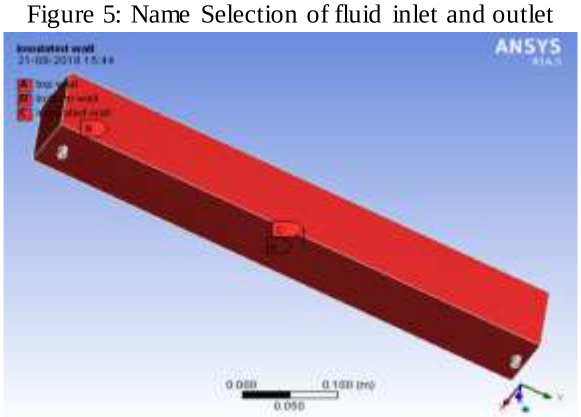

Figure 6: Name Selection of solar water heater

Model Selection

In model selection only three parameters are selected. Remaining parameter are remained as default. The three parameters are:-

Model TYPE-3D,Energy-On,Radiation- Rosseland, Density- Boussinesq, Solution-Pressure Presto, Momentum- Second order, Energy –Second order, No. of iteration-500,Solution converged -8

Material Selection

Physical Properties* for the copper (Cu) considered for this study are as below:

Table 4 Properties of collector tube

S. No	Particle	Thermal conductivity (W/m-K)	Density (Kg/m^3)	Specific Heat(J/Kg-K)
1.	Cu	46	3970	390

Boundary Condition

Table 5: Boundary condition of different parameters

Name	Mass Flow rate (Litre/day)	Temperature(^{o}C)
Inlet Fluid	25	34
Hot Fluid	25	76.4

Collector inclination angle = 300C

Fluid to tube heat transfer coefficient = 205W/m2 oC

IV. RESULTS AND DISCUSSIONS

Heat transfer through solar water heater depends on the mass flow rate and temperature of fluid flowing inside the flat plate solar heat exchanger. In current flow rate of 25 litres/day have been considered. Fins are provided on the tube is kept rectangular to maximize the area of heat transfer. To analyze the effect fins on the heat exchanger rate, the CFD model of solar water heater has been developed.

Calculation Involved

The amount of heat transferred from the hot water and the amount of heat transferred to the cold water are evaluated using the following relations,

Q_h=m $\times$ c_p $\times$ (T_i − T_o)

Wattage heater = (m$\times$ c_p $\times$ (T_i-T_o)/Δt)

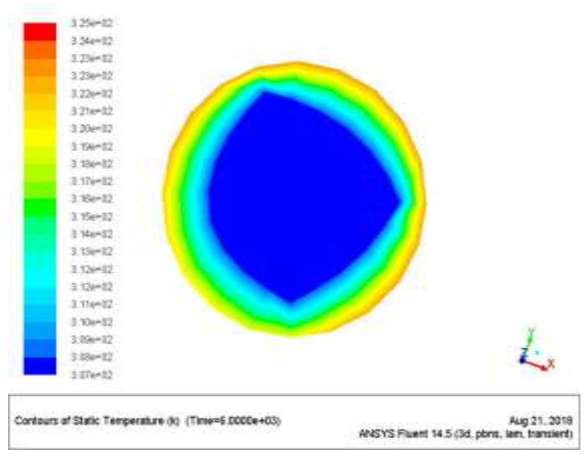

Figure 7: Temperature Contours at outlet for solar water heater.

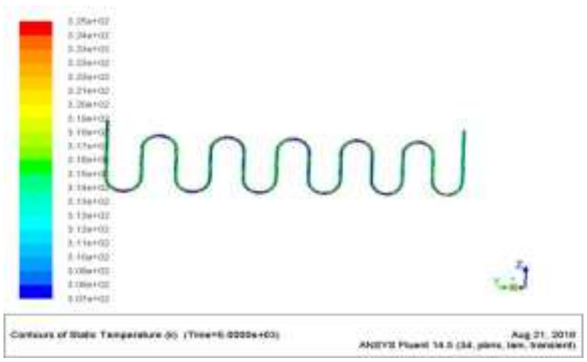

Figure 8: Temperature Contours at 100 minute for solar water heater

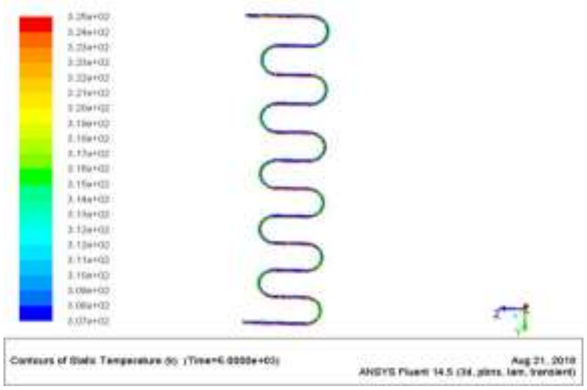

Figure 9: Temperature Contours at 100 minute for solar water heater

Table 6: Temperature variation along with time.

Time(in Minute)	Temperature (in ^{0}C)	
	Without Fin (Previous work)	With Fin (Present work)
0	33.9	33.9
20	39.2	41.2
40	41.5	44.3
60	43.2	48.7
80	46	52.9
100	47.2	56.5

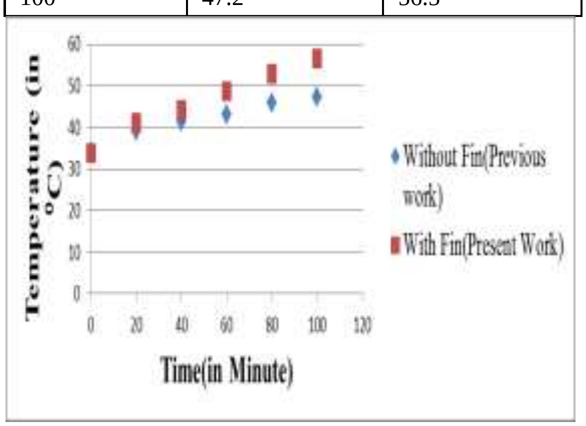

Figure 10: Temperature variation along with time.

Calculation of collector efficiency (complete cycle)

The efficiency of SWH is calculated for trail for given period of heating time of 100 minute similar to considered in experimental setup:

Total heating time =100 min

ΔT achieved in experimental set up = (47.2-34) =13.2

ΔT achieved in experimental set up = (56.5-34) =22.5

Mass of water =25Kg

Q heater = m*C_p= 1674.8 KJ

C_p of water =4187 J/Kg^{o}C

Wattage heater with fin =Q/t = 700.21Watts

Wattage heater with experimental setup =Q/t = 279 Watts

Average solar power in India is =5KW/m^2

Surface area of the collector = 0.3542 m^2

Net solar power incident on collector surface = (5*0.3542*cos30) = .273KW/m^2

Efficiency of solar collector with fin = (($Wattage_{with\ fin}$ -$Wattage_{without\ fin}$)/ $Wattage_{with\ fin}$)*100

So efficiency = (421/700.21)*100= 60.124%

V. CONCLUSIONS

- The solar collector model thus produced was put to test by simulated effect of radiation due to sun, while circulating water through it at constant mass flow rates, the evacuated tubes are imparted with fin.
- The SWH efficiency was as high as 60.124 % as compared to SWE with simple tube. These types of solar water heaters can easily be used to heat pool water.
- A flow rate comparable to that of .2lpm is best for heating. The heaters are to be used intermittently for heating a batch of water till 15-20 minutes until the efficiency drops down and then fresh water be circulated through it.
- A cycle like this would give us the maximum output in minimum time.

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